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INTERFACING THE ANALOGIC 6000A WAVEFORM ANALYZER TO THE XM21 CHEMICAL REMOTE SENSOR

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This report describes an electronic interface from the XM21 chemical remote sensor to the Analogic Waveform Analyzer (WFA). The XM21, an emission Fourier Transform Infrared (FTIR) Spectrometer, indicated the presence of an infrared active vapor in a stand-off detection scenario. The Analogic 6000A WFA permits data acquisition from the FTIR Spectrometer in a variety of formats. However, data acquisition from the XM21 with the WFA requires software and hardware interfacing, which is documented in this report.

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PREFACE

The work described in this report was authorized under Project No. 1L161102A71A, Research in CW/CB Defense. This work was started in October 1988 and completed in November 1989.

The use of trade names or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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INTERFACING THE ANALOGIC 6000A WAVEFORM ANALYZER
TO THE XM21 CHEMICAL REMOTE SENSOR

1. INTRODUCTION

The XM21 is a Fourier Transform Infrared (FTIR) Spectrometer that is based on a Michelson interferometer. The XM21 operates in the 8 to 12 μ region of the radiation spectrum. This spectral region is one of two atmospheric windows that permits the use of FTIRs for chemical standoff vapor detection. Detection of a compound in this spectral region with the FTIR requires that the compound of interest possess a dipole moment. Many compounds of interest meet this criteria. Identifying pollutants present in the atmosphere is often possible. The purpose of this report is to describe a procedure for obtaining vapor phase data from the XM21 Remote Sensor with an Analogic 6000A Waveform Analyzer (WFA) (Analogic Corporation, Peabody, MA). This approach permits acquisition of data in a variety of formats that depends upon the sensor application.

2. FTIR DESCRIPTION

A brief description of the XM21 relevant for interfacing to the WFA is given. The XM21 implements the Michelson interferometer optical design. The Michelson interferometer consists of an optical beam splitter, fixed mirror, and moving mirror (Figure 1). Radiation entering the interferometer's optical train interacts at the beam splitter in a constructive or destructive manner dependent upon the relative positions of the two mirrors. For a predefined mirror movement, this optical interaction generates a data pattern in time that is called an interferogram (INTEF) (Figure 2a). The INTEF pattern depends on input radiation characteristics of coherence and chromaticity. Radiation from a helium neon (HeNe) laser represents a monochromatic source (i.e., 0.6328-μm wavelength), with a coherence length approximately two orders of magnitude larger than the interferometer mirror optical retardation of 0.25 cm (i.e., wavenumber resolution of four). Thus, the resultant INTEF for HeNe laser radiation is an undamped cosine wave pattern (Figure 2b). On the other hand, INTEFs of incoherent and chromatic radiation [e.g., white light or blackbody infrared (IR) sources] consist of a superposition of many cosine/sine wave components (Figure 2). The superposition results in a large interference pattern near the zero path difference (ZPD) of the interferometer (i.e., position where the mirror distances from the beam splitter are nearly equal). This INTEF region near ZPD is called the centerburst. An increasingly smaller pattern occurs upon mirror displacement away from ZPD. Zero crossings of the HeNe laser cosine wave pattern mark equal increments of the moving mirror displacement from ZPD.

The laser zero crossings serve to optically indicate sampling times for data collection of the IR INTEF. Figure 2c shows the signal $\overline{\text{CLOCK}}$ that indicates when to sample the IR INTEF. The signal $\overline{\text{CLOCK}}$ is only active when a valid IR INTEF is present. An INTEF that is generated from a white light radiation source produces the signal status (SSTAT). The SSTAT indicates when to begin sampling the valid IR INTEF. The XM21 provides the SSTAT, during which $\overline{\text{CLOCK}}$ is also generated. The XM21 also implements the necessary analog filtering of the detector signal to avoid aliasing effects. Design of

antialiasing filters for FTIRs depends on the following major considerations: interferometer mirror velocity, detector spectral response, and signal dynamic range.[1,2] Because the antialiasing filter comprises a portion of the XM21, we assume a filtered IR INTEF signal is available for use by the WFA.

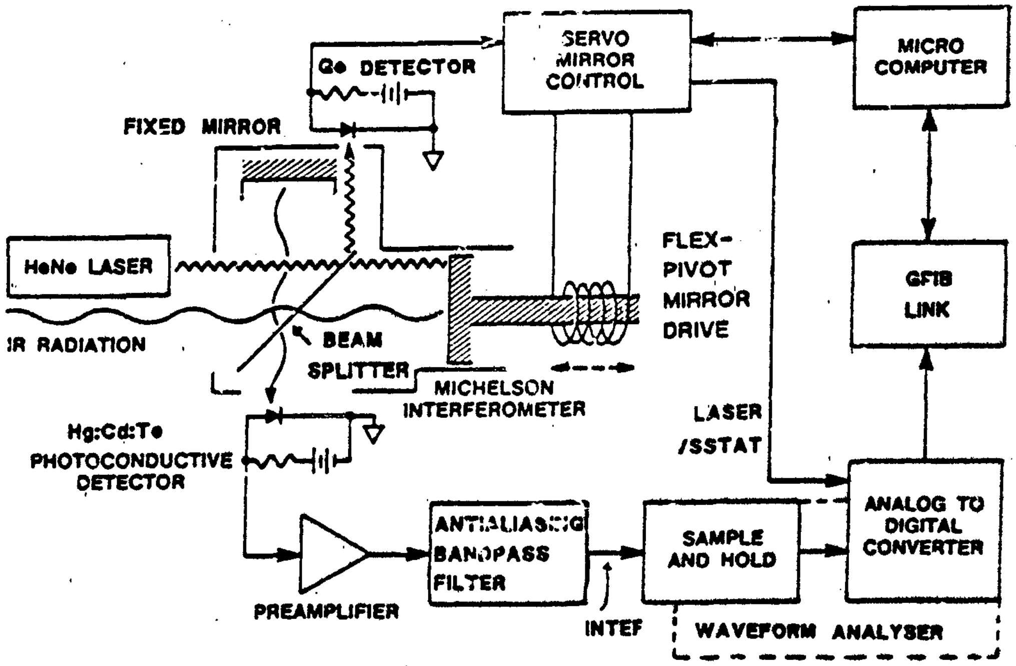

Figure 1. Components of an FTIR Spectrometer Used for Standoff Vapor Detection

3. INTERFACE CIRCUIT DESCRIPTION

The necessary interfacing signals for data collection from the XM21 with the WFA are LASER (a mirror position indicator), SSTAT (a flag indicator of valid IR data available), and INTEF (the amplified/filtered IR detector signal). The INTEF connects directly to channel one of the WFA. Because INTEF is already available to the WFA, the interface requires only LASER and SSTAT as inputs. The interface circuit with inputs of LASER and SSTAT consists of a high speed voltage comparator and associated digital timing electronics. The schematic wiring representation of the interface is viewed in Figure 3. The table lists the various circuit element values and designations that are found in Figure 3. The high speed voltage comparator, IC_1B, performs a zero crossing function. A zero crossing function converts the approximately 2 V peak-to-peak (Vpp) cosine LASER signal into a transistor-transistor logic (TTL) (i.e., 0 to 5 V) square wave signal. The complementary outputs of the comparator triggers a dual positive edge monostable, IC_2B. The monostable, with a time constant of approximately 0.5 us, generates two clock pulse trains at outputs 1Q and 2Q. A NOR gate, IC_3B, combines the monostable outputs at 1Q and 2Q, producing the signal $\overline{\text{CLOCK}}$ with a period of 12 us. The inversion of this signal is labeled CLOCK (Figure 3) and drives the EXT CLOCK input of the WFA for data collection.

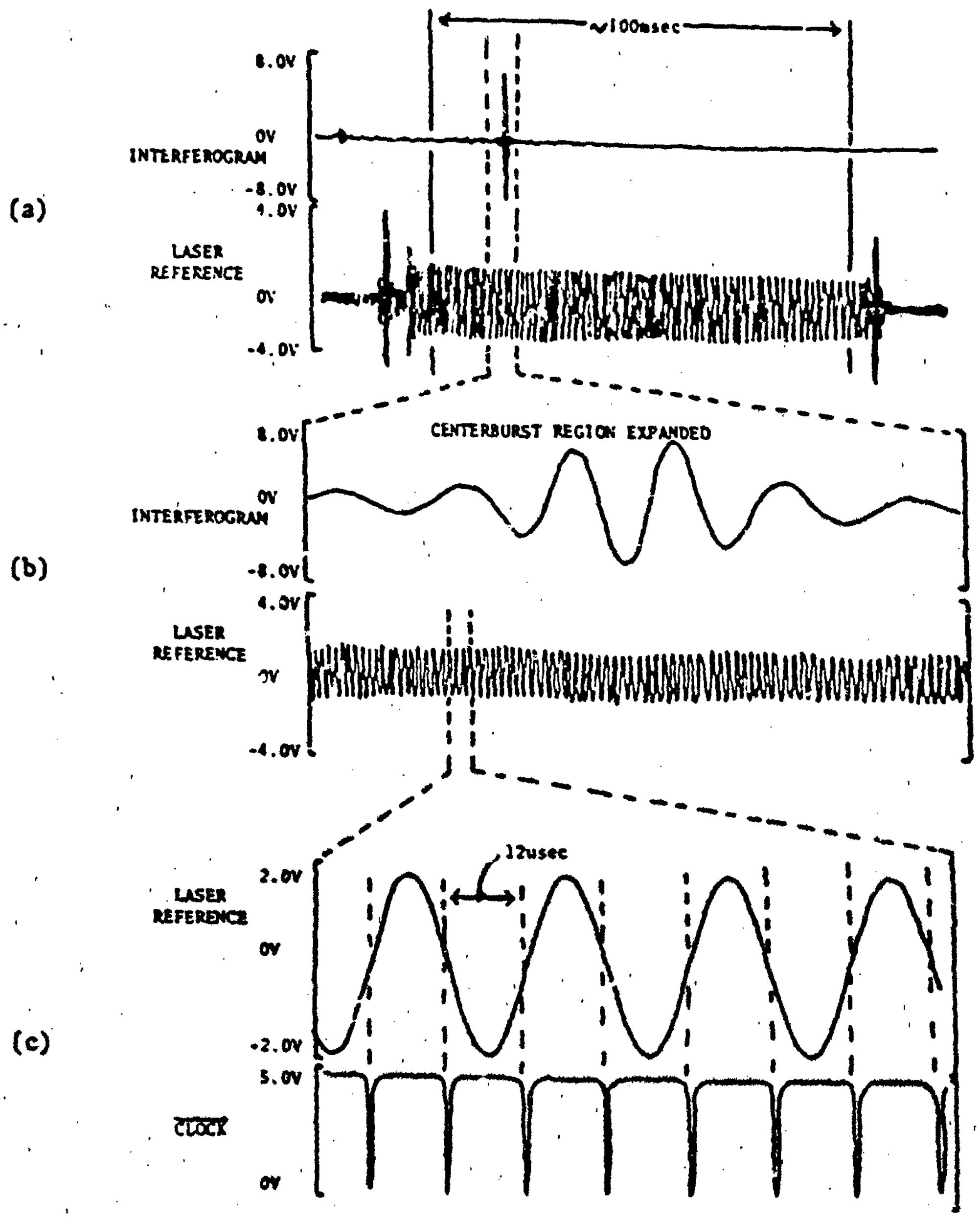

Figure 2. Interference Patterns (i.e., INTEFs) for IR Radiation Source and a Coherent HeNe Laser Source. The HeNe source permits IR signal sampling by generation of the TRIGGER signal CLOCK. Trace (a) shows one complete interferometer scan. Trace (b) expands the INTEF centerburst region. The top portion of trace (c) plots the LASER signal while the lower portion of (c) is the generated CLOCK sampling signal.

The effect of noise on the signal $\overline{CLOCK}$ is illustrated in Figure 4. A 1.6 Vpp cosine input is generated with the Analogic Model 2020 Polynomial Waveform Synthesizer (Analogic Corporation) at a frequency of 40 KHz that is comparable to the XM21 LASER signal. No erroneous triggering of $\overline{CLOCK}$ is observed until the noise amplitude reaches approximately 0.16 Vpp as shown in Figure 4b. This noise level is approximately 10 times greater than the noise on the FTIR LASER signal. Noise tolerance of IC 1B depends on the amount of hysteresis specified by values of resistors R4 through R7 (conversation with Wanda Garrett, National Semiconductor, Santa Clara, CA, May 1989).

Table. Interface Circuit Component Values and Designations

IC number	Description	Power Supply Pin Connections +12 V	+5 V	GND	-12 V
1A	LM339	3	12	X	X
2A	74LS04	X	14	7	X
3A	74LS74	X	14	7	X
4A	74LS08	X	14	7	X
1B	LM361	1	14	10	6
2B, 1C	74LS123	[illegible]	16	8	X
3B	74LS02	X	14	7	X
4B, 4D	7495	X	14	7	X
2C	74LS193	X	16	8	X
3C	74LS14	X	14	7	X
4C	74LS93	X	14	7	X

Resistor	Resistance value (Kohms) 5% carbon film	Capacitor	Capacitance value (uFD) 25 V ceramic disc
R1	1.200	C1, C3, C5	0.010
R2, R3, R12, R13	1.100	C7, C9, C11	0.010
R4, R5, R11, R14	1.000	C13, C14, C15	0.010
R6, R7	1000.000	C2, C4, C6, C8	0.100
R8, R9	30.000	C10, C12, C18	0.100
R10	0.390	C16, C17, C19	0.001

Component	Description
SW1	SPDT Momentary Switch
LED	P309, Panasonic 30 ma Clear green light emitting diode

Connectors

BNC
TSC
Power Terminator Block

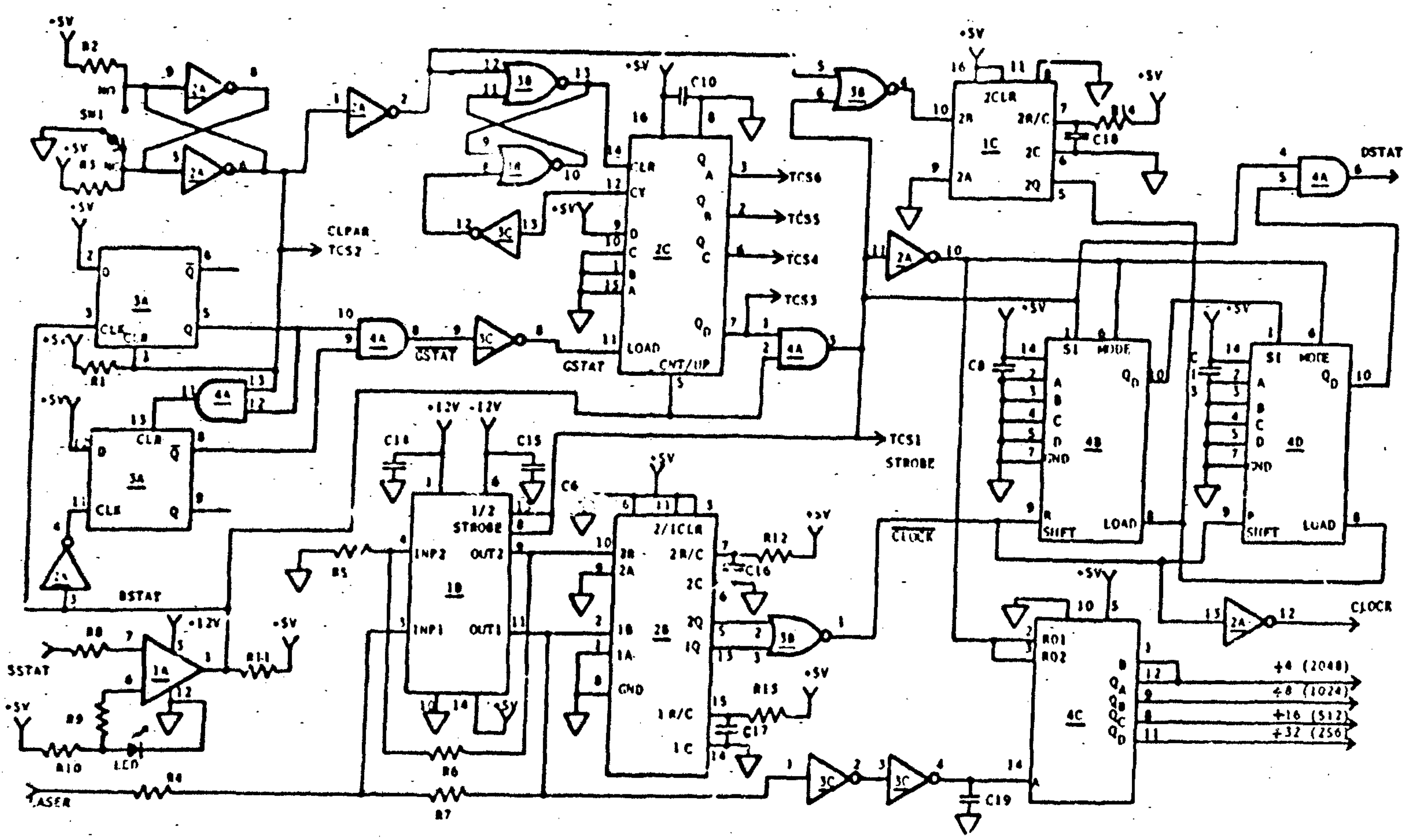

Figure 3. Electronic Wiring Schematic for an Interface from a Michelson Interferometer to an Analogic 6000A WFA

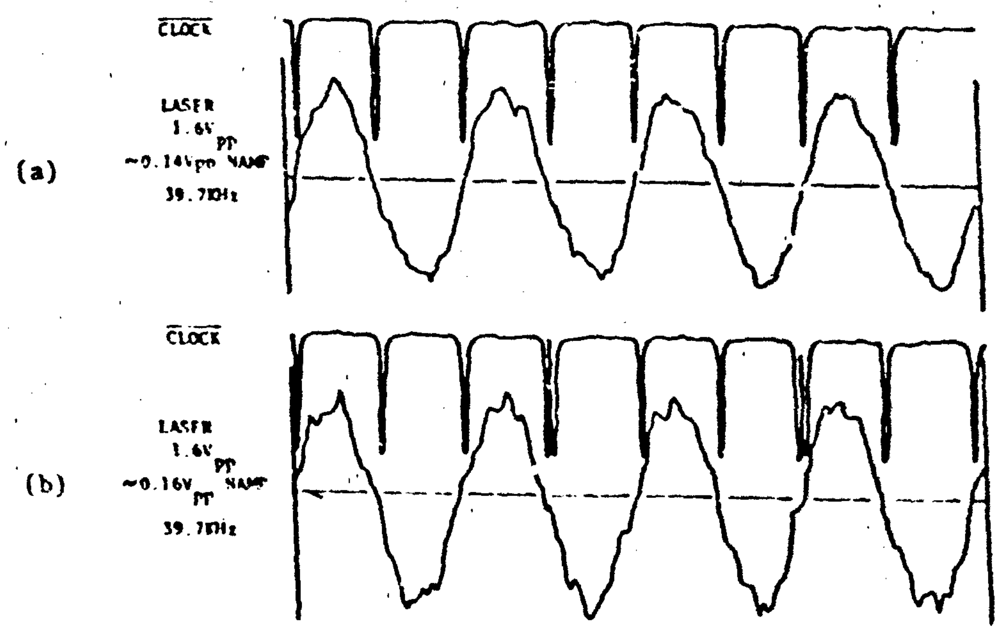

Figure 4. Noise Immunity of the LM361 Voltage Comparator. This noise immunity depends on the hysteresis level set with resistors R4 and R7. Trace (a) shows no missed TRIGGERs of CLOCK while trace (b) indicates the noise amplitude has exceeded the hysteresis level with two CLOCK TRIGGER errors apparent.

The remaining circuitry (Figure 3) provides timing synchronization between the WFA and XM21 with the generation of the signal DSTAT. The DSTAT signal indicates when a valid IR INTEF signal is available from the FTIR and provides input to the TTL TRIGGER input of the WFA. Data collection sequence initiation begins with closure of the debounced switch SW1. This switch clears one half of the data latch IC_3A and sets the RS flip-flop output to ground that is tied to the $\overline{\text{CLEAR}}$ pin of IC_2C. The buffered version of SSTAT (BSTAT) subsequently produces the gated version of SSTAT (GSTAT) as shown in the timing diagram (Figure 5). The GSTAT signal loads the up/down counter, IC_2C, with a binary bit value of eight. This loading initializes test point $\overline{\text{TCS3}}$ to a logic one. The most significant counter output remains at logic one for a set of eight positive BSTAT transitions on the count up pin of IC_2C. The BSTAT signal is gated by TCS3 with an AND gate, and this gated signal is called STROBE on TSC1. STROBE provides eight enable pulses after SW1 closure. On the eighth BSTAT transition, the counter is cleared by a self-generated carry signal that resets the RS flip-flop that is connected to the $\overline{\text{CLEAR}}$ pin of IC_2C. STROBE is subsequently disabled by a logic zero at TCS3 of the counter that gates the BSTAT signal. The train of eight STROBE pulses (Figure 5) permits generation of the $\overline{\text{CLOCK}}$ signal only when SSTAT is active. The set of consecutive pulses on STROBE offers the possibility of signal averaging for improving the IR INTEF signal-to-noise ratio (SNR) by the $\sqrt{8}$. The WFA requires several pulses on EXT CLOCK input before a TRIGGER signal is accepted on TTL TRIGGER input. A HP16500A Logic Analyzer (Hewlett-Packard, Rockville, MD) with a 16520 pattern generator permits documentation of this interaction between EXT CLOCK and TTL

TRIGGER inputs. Two shift registers are used to permit a delay in STROBE that is consistent with the TTL TRIGGER input requirements of the WFA. This delayed STROBE is designated as DSTAT. The shift registers, IC_4B and IC_4D, are loaded with zeros on the rising edge of the CLEAR signal or on the falling edge of the STROBE using a NOR gate, IC_3B, and the monostable, IC_1C. STROBE enables the shift registers with an active logic one. STROBE also supplies a serial input into shift register, IC_4B. The Qd output of shift register, IC_4B, provides the input for the second cascaded shift register, IC_4D. The Qd output of IC_4D gates the STROBE through an AND gate, producing the DSTAT signal. When the STROBE becomes an active logic one, eight $\overline{\text{CLOCK}}$ pulses to the SHIFT RIGHT inputs of the shift registers are necessary before the DSTAT signal becomes active. This is illustrated with an expanded timing diagram of the first 0.1 ms of the STROBE pulse in Figure 5b. An expansion of signals for the first active STROBE are only shown, because the same timing sequence results for each successive STROBE pulse.

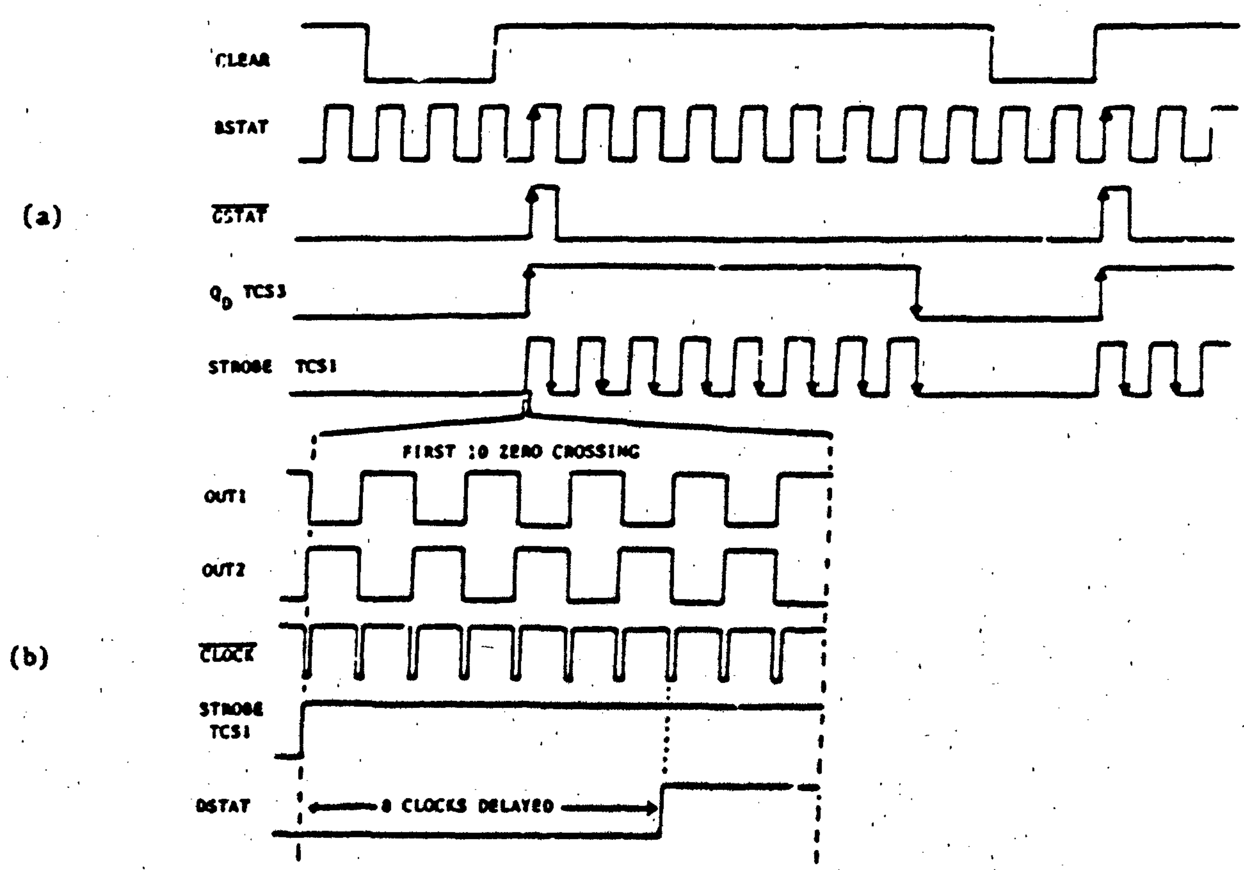

Figure 5. Timing Diagram. Timing diagram (a) shows the generation of eight sequentially delayed STROBE pulses (i.e., DSTAT) that indicate a valid IR INTEF is available for collection. In timing diagram (b), each STROBE pulse is delayed by eight CLOCK pulses to produce DSTAT necessary for WFA operation.

Using the binary counter, IC_4C, other IR INTEF sampling rates are possible with the circuit illustrated in Figure 3. The IC_4C provides divided versions of the CLOCK signal used for IR INTEF sampling. The sampling rate is dependent on the antialiasing filter that is implemented in the XM21. The XM21 contains an antialiasing filter that only requires sampling at every fourth positive going laser fringe (i.e., every eighth LASER zero crossing). This sampling is available on the output signal of IC_4C labeled ÷8_(1024). The ÷8 indicates a divided CLOCK signal that is eight times longer in duration, and (1024) designates a resulting file length of 1024 points. To implement this sampling rate, IC_4C pin nine must be substituted for IC_3B pin one. The substitution generates a new DSTAT signal that is delayed by eight of the ÷8_(1024) clock pulses, and a new CLOCK pulse is generated on every eighth LASER zero crossing. Other divided down outputs are also available of IC_4C, and the usage depends on the antialiasing bandpass filter that is implemented.

4. INTERFACE CIRCUIT ASSEMBLY

The described interface assembly (Figure 3) on a prototype wire wrap board, as well as the component and wire views of component placement on the protoboard, are shown in Figure 6. Power supply connections are made with Vector T112-2 (Vector Electronic Company, Sylmas, CA) spring bus links. These bus links are placed over wire wrap socket supply pins and are fitted snugly against the plastic housing before soldering. Once bus links are attached to the sockets, the sockets are inserted and attached to the protoboard. Subsequently, the power supply lines are soldered to the extended bus tabs on top of the protoboard. Power supply lines are routed to a terminator block on the component side of the protoboard. This approach isolates the major power supply connections on top of the protoboard. The Berkeley Nucleonics Corporation (Berkeley, CA) connectors permit easy access to interface signals from the component side of the protoboard. Resistor and capacitor components are mounted with Vector T44 pins. Wire interconnections on the wire side of the protoboard between components are made with standard wire wrap techniques.[3]

5. DATA COLLECTION

Implementing the interface from the XM21 to the WFA is facilitated using the IEEE-488 bus that is provided on the WFA. A GPIB-PCII card and software developed by National Instrument Corporation (NIC) (Austin, TX) allows connection to a compatible IBM PC over the general purpose interfacing bus (GPIB) link. The compatible IBM PC with the GPIB card permits downloading of programs and settings to the WFA, as well as uploading of data collected by the WFA. The hardware and software details for using the GPIB-PCII card are covered in the User's Manual.[4] However, consideration of three programs written in NIC's Interface Bus Interactive Control (IBIC) language is useful in describing operation of the interface circuitry. The IBIC commands can also be incorporated into programming languages such as C, BASIC, and FORTRAN as subroutines. For simplicity, we use only the IBIC commands that are generated from an ASCII source file. Once in IBIC, the source file is executed by typing a dollar sign followed by the filename. Only five IBIC commands are used in the three programs to be described. These commands are as follows: IBFIND opens up the device connected to the GPIB, IBTMO sets a device response time

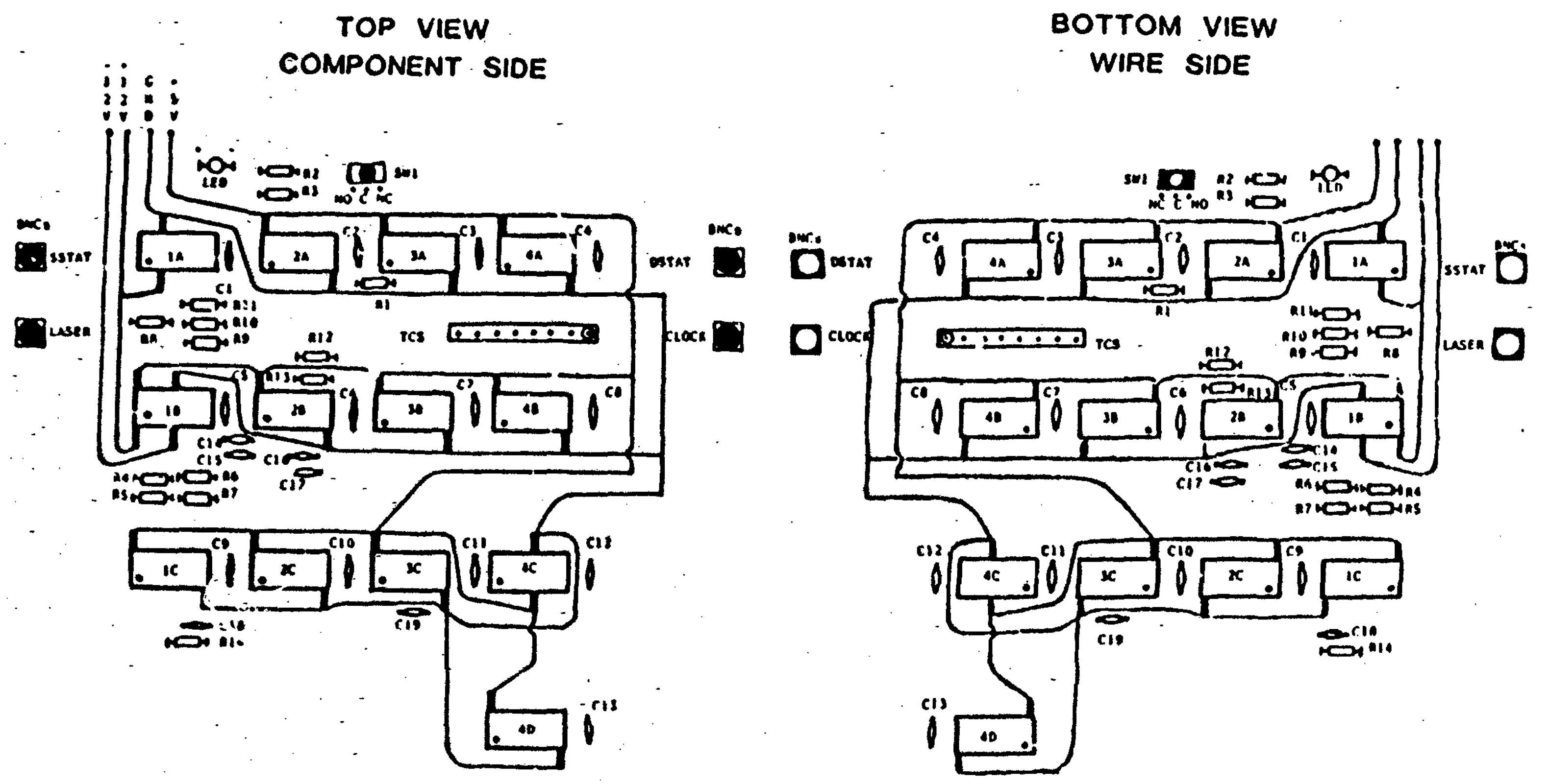

Figure 6. Interface Layout and Component Placement on a Wire Wrap Protoboard

limit, IBWRT writes a data string over the GPIB, IBRDF reads data from the specified device into a DOS file, and IBLOC closes down the device connected to the GPIB.

The program SETUP.IC in Program Listing 1 initiates the Model 650-1 Plug-in Unit of the WFA. The device is opened with the command IBFIND D6000, and a time out limit of 3 s is set with the command IBTMO 12. The IBWRT commands contain ASCII strings that are equivalent to the key closures and field settings illustrated in the right hand portion of Program Listing 1. The key closure, DARM, disarms the WFA. The key closures that follow DARM provide the formatting for display (DISP), input (INP), triggering (TRIG), and timebase (TMB) functions. Each of the softkey fields associated with a given function are set with the proper mnemonic given in the Model 650-1 and 652-1 User's Manual.[5] The display is designated as single trace containing BUF.A1. Input is defined only on Channel one. Triggering the WFA with the DSTAT signal from the interface connected to TTL TRIGGER requires positive edged and TTL compatible settings. Connection to the CLOCK signal from the interface to the EXTERNAL CLOCK input of the WFA requires the timebase to be set to +EXTCLK. The number of data points to be collected is defined in field three of the TMB mode for the CLOCK signal. Finally, the device is closed down from the GPIB with the IBLOC command. Once SETUP.IC completes initialization of the WFA, the next step in operation is to key in a program for collecting eight sequential IR INTEFs.

The program ACQUIRE.IC for the WFA (Program Listing 2b) is downloaded over the GPIB link with the 175-line program on the IBM PC that is given in Program Listing 2a. Program Listing 2a contains KEY codes that are equivalent to pressing keys on the FUNCTION KEYPAD. The Program listing 2a contains line numbers because the printout is from a line editor. Each four digit key code command corresponds to the symbol written adjacent to the IBIC program command and separated by a line. These symbols represent the necessary key strokes to input the program of Program listing 2b into the WFA. The program in Program listing 2b first arms the WFA and then collects eight sequential files before terminating with a STOP. The interspersed WAITAQ commands hold program execution until the current data acquisition is completed. After execution of ACQUIRE.IC on the WFA, a set of eight IR INTEFs are present in files A through H. Once these files are collected, transmission over the GPIB link permits data storage on the IBM PC.

The program COLLECT.IC in Program Listing 3 permits uploading a file that resides in the primary trace of the WFA's display. This file may be any one of the previously collected A through H files or the BUF.AI file. The binary file format from the WFA is that of the Motorola (Tempe, AZ) 68000. In the Motorola format, the first byte of the 16-bit word is the most significant 8 bits, and the second byte is the least significant 8 bits. For processing on a compatible IBM PC, the byte order must be reversed to be consistent with the Intel format. We chose to use a compatible IBM PC for data storage and further processing with a software package called SPECTRA CALC that is designed specifically for spectroscopic analysis.[6] SPECTRA CAL provides a software interface to many commercially available FTIRs and supports features that are used for various spectroscopic data display/processing operations.

```
IBFIND D6000
IBTMO 12
IBWRT "DARM"
IBWRT "DISP"
IBWRT "DSPM = 1"
IBWRT "TRACE = 1"
IBWRT "TRCSRC = BUF.A1"
IBWRT "INP"
IBWRT "INPSEL = 1"
IBWRT "COUPLE = DC"
IBWRT "RANGE = 5"
IBWRT "PROBE = 1"
IBWRT "TRIG"
IBWRT "TRGTYP = 1"
IBWRT "TRGSRC = 6"
IBWRT "TRGLEV = 1.75V"
IBWRT "TRGSLP = 1"
IBWRT "TMOD = 2"
IBWRT "TMB"
IBWRT "TMBSEL = 1"
IBWRT "NSWP = 1"
IBWRT "NPTS = 8192"
IBWRT "PERSRC = 2"
IBLOC
```

Setup program in IBIC for WFA

KEY	FIELD1	FIELD2	FIELD3	FIELD4	FIELD5
DARM / DISP	TRACE 1	SOURCE BUF.A1			DSPL MODE SINGLE
INP	INPUT CH1	RANGE +10V	PROBE X1	COUPLE DC	
TRIG	TYPE EDGE	SOURCE EXTLOGIC	LEVEL 1.75000V	SLOPE +	MODE NORMAL
TMB	TIMEBASE A	#SWEEPS 1	#POINTS 8192	PERIOD +EXTCLK	DELAY 0.00000C1

Key closures with field settings on WFA equivalent to setup program.

Program Listing 1. SETUP.IC (SETUP . INTERFACE CIRCUIT). Setup for data collection with the Analogic from the interferometer and associated interface.

```
IBFIND D6000
IBTMO 12
IBWRT "PROG"
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2024"   R
IBWRT "KEY = 2019"   M
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2009"   C
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2010"   D
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
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IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2011"   E
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2013"   G
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2040"   W
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2015"   I
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2023"   Q
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2014"   H
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2045"   =
IBWRT "KEY = 2006"   SP
IBWRT "KEY = 2008"   B
IBWRT "KEY = 2030"   U
IBWRT "KEY = 2012"   F
IBWRT "KEY = 2043"   .
IBWRT "KEY = 2007"   A
IBWRT "KEY = 2037"   1
IBWRT "KEY = 2001"   CR
IBWRT "KEY = 2004"   ∝
IBWRT "KEY = 2025"   S
IBWRT "KEY = 2026"   T
IBWRT "KEY = 2021"   O
IBWRT "KEY = 2022"   P
IBWRT "KEY = 2001"   CR
IBLOC
```

Program Listing 2a. ACQUIRE.IC on the IBM PC. Downloading a program call d ACQUIRE.IC from the compatible IBM PC over the GPIB into the Analogic 6000A.

Acquire program on the WFA	Comments
10 ARM	Arm the WFA
20 WAITAQ	Wait for current acquisition to complete
30 A = BUF.A1	Acquire data in buffer and transfer to A
40 WAITAQ	Wait for current acquisition to complete
50 B = BUF.A1	Acquire data in buffer and transfer to B
60 WAITAQ	Wait for current acquisition to complete
70 C = BUF.A1	Acquire data in buffer and transfer to C
80 WAITAQ	Wait for current acquisition to complete
90 D = BUF.A1	Acquire data in buffer and transfer to D
100 WAITAQ	Wait for current acquisition to complete
110 E = BUF.A1	Acquire data in buffer and transfer to E
120 WAITAQ	Wait for current acquisition to complete
130 F = BUF.A1	Acquire data in buffer and transfer to F
140 WAITAQ	Wait for current acquisition to complete
150 G = BUF.A1	Acquire data in buffer and transfer to G
160 WAITAQ	Wait for current acquisition to complete
170 H = BUF.A1	Acquire data in buffer and transfer to H
180 STOP	Terminate program execution

Program Listing 2b. ACQUIRE.IC on the WFA. This program on the Analogic 6000A acquires eight sequential IR INTEFs for later transfer to the compatible IBM PC.

IBIC Commands	Comments
IBFIND D6000	Open device D6000/Analogic 6000A
IBTMO 12	Disable time limit 12 = 3 seconds
IBWRT "DARM"	Write string "DARM" i.e. press DARM
IBWRT "DISP"	Write string "DISP" i.e. press DISP
IBWRT "FLDDLM = SP"	Field delimiter is a space
IBWRT "FORMAT = BINARY"	Data in binary Motorolla 68000 form
IBWRT "LINEND = NONE"	Line end response not set
IBWRT "DISP"	Write string "DISP" i.e. press DISP
IBWRT "SRC"	Request primary display trace
IBRDF C.DAT	Read data into a MS-DOS file, C.DAT
IBLOC	Relinquish control to WFA

Program Listing 3. COLLECT.IC. Data Collected in the primary trace of the Analogic 6000A is transferred with this program via the GPIB link to the compatible IBM PC for data storage as a MS-DOS file.

A standard approach to processing INTEFs is illustrated in Figures 7 and 8. Figure 7a plots the first 200 points of a 1024-point INTEF. Each INTEF point is collected on the eighth zero crossing of the HeNe LASER cosine wave signal. The time domain IR INTEF is transformed into the frequency domain with a fast fourier transform (FFT) program. A plot of transformed data from 500 to 1600 cm^{-1} that gives the detector response envelope is found in Figure 7b. The spectral band centered at 940 cm^{-1} in Figure 7b indicates the presence of sulfur hexafluoride (SF_6). Removal of the broadband Hg:Te:Cd detector envelope from the narrowband SF_6 feature results upon background subtraction, which entails subtracting a spectrum with no SF_6 from a spectrum containing SF_6. This procedure gives different spectra that are shown in Figure 8. Figure 8a results from the background subtraction for a single interferometer scan; whereas, Figure 8b is the difference result of four coadded INTEFs. The SNRs for the single scan and four coadded scans are 5.7 and 12.6, respectively. The noise used in calculating the SNRs is the peak-to-peak value measured from 850 to 900 cm^{-1}. The theoretical enhancement of the SNR for coadditions over a single scan follows the square root of the number of coadditions. Therefore, four coadditions implies an enhancement of two that is consistent with the ratio of the SNRs of 2.2 calculated from the spectra in Figure 8. Signal averaging is the traditional approach in FTIR for improving the SNR under weak signal conditions that are produced with a constant input IR radiation source.

6. SUMMARY

In conclusion, this report provides a procedure for obtaining IR interferometric data from the XM21 with an Analogic 6000A WFA. The interface circuitry and associated programs for IR INTEF collection are described in detail. The advantage of such a procedure over vendor supplied acquisition hardware and software is the ability to customize the approach to a specific interferometer application. Collecting data in binary integer format provides flexibility in signal processing and preserves the raw data format for further analysis. Recovery from errors in processed data due to inappropriate manipulation (e.g., Fourier transform windowing) is insured by this approach.

Future considerations and improvements in the described approach are two fold. First, the circuitry (Figure 3), which is used for timing, may benefit from using programmable logic devices (PLDs). The PLDs can eliminate the need for hardware modifications for different clock rates with the appropriate state machine implementation. Second, the programs using the GPIB provide much more versatility if incorporated into a program language such as C or BASIC. Clearly, the Program Listing 2A for ACQUIRE.IC can be reduced in size with the string handling capabilities of a high level language. A program command on the WFA is a list of codes on the FUNCTION KEYPAD. To generate the codes necessary for the FUNCTION KEYPAD of the WFA, a language such as C or BASIC can assign individual KEY code values to the characters in a string such as "WAITAQ" before calling the IBWRT subroutine.

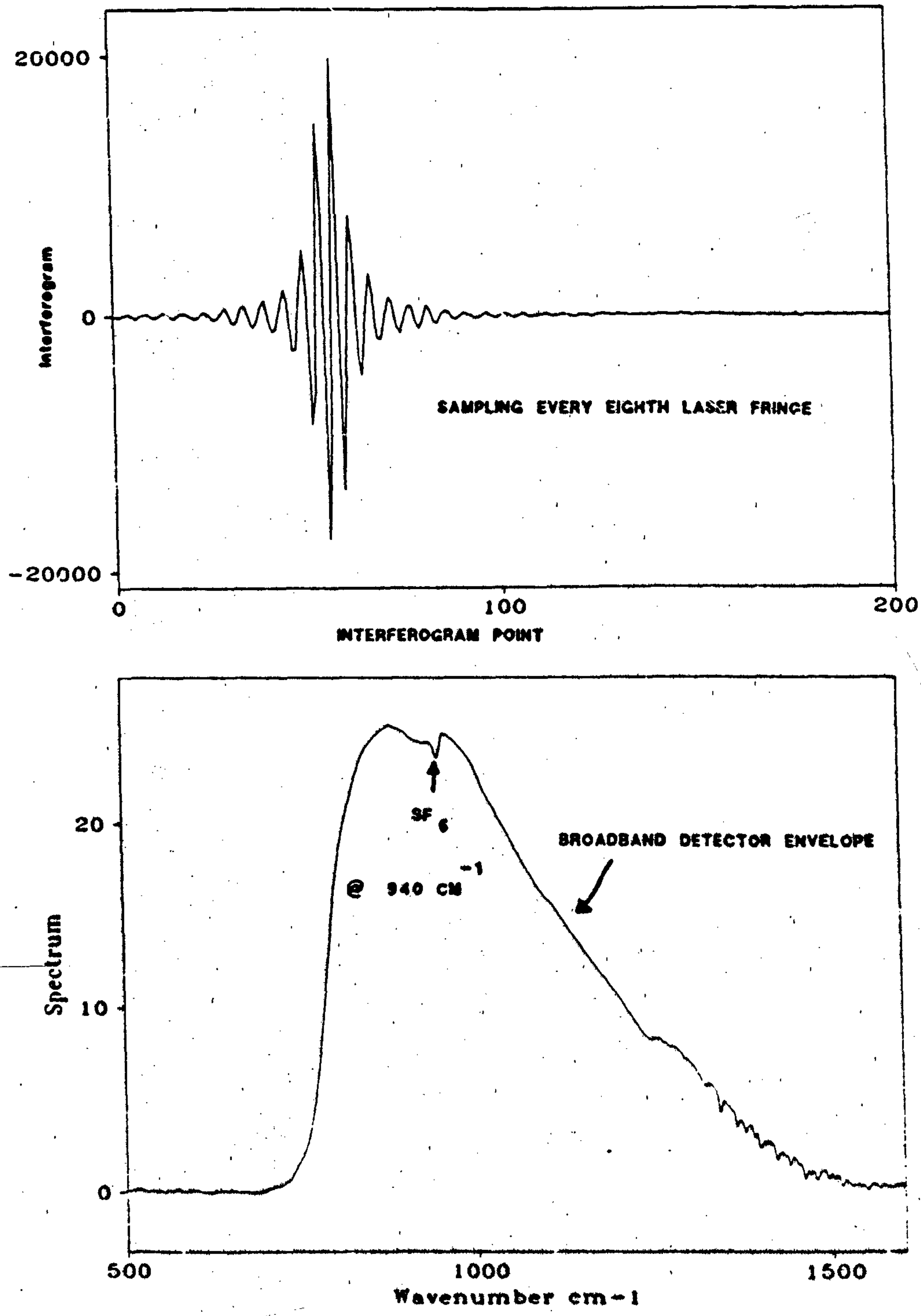

Figure 7. INTEF Transformation. Transformation of an INTEF (a) in the time domain into a spectra (b) in the frequency domain using an FFT is the traditional method of data processing with FTIRs.

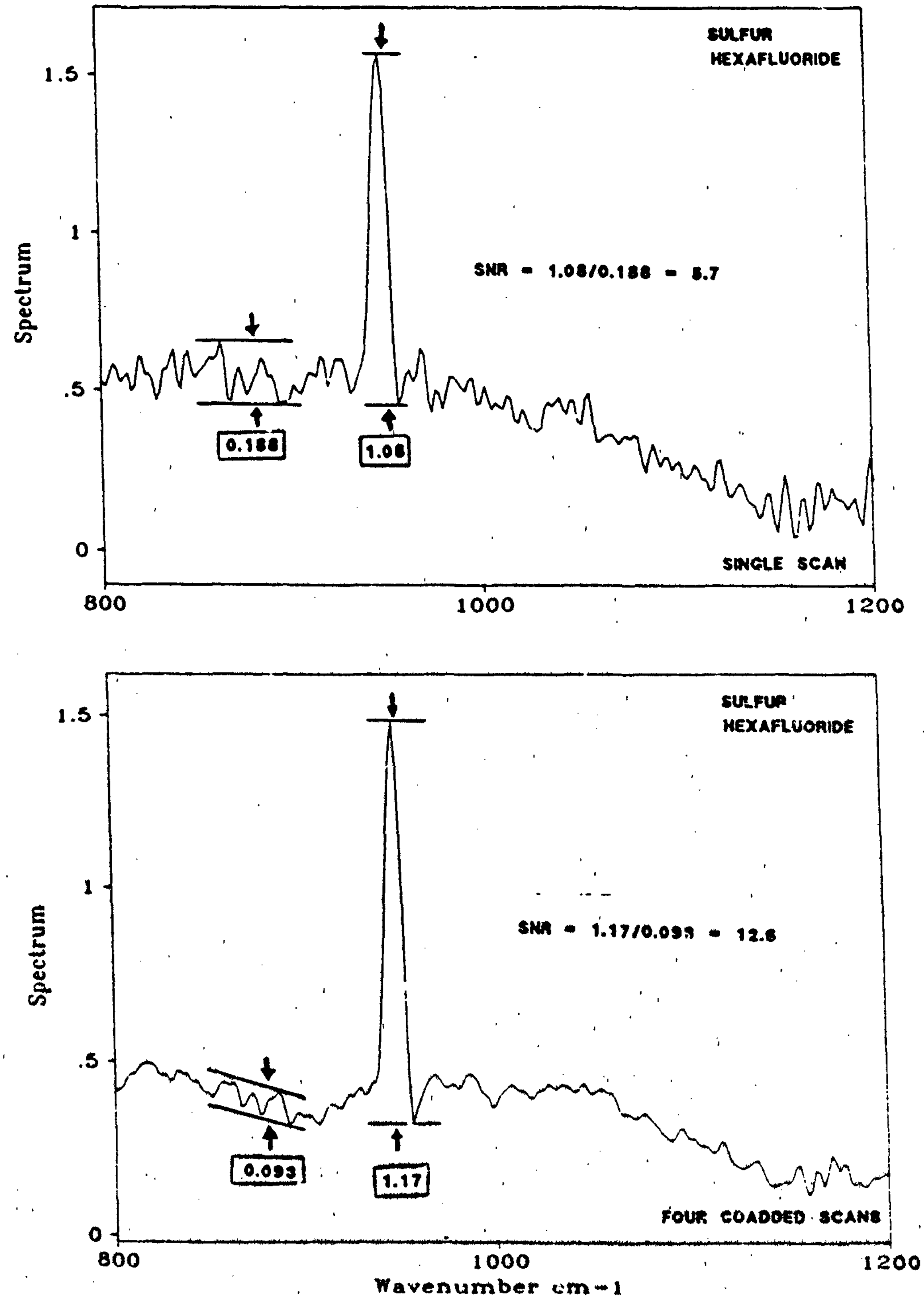

Figure 8. Background Subtraction of an Empty Cell INTEF from a Sample Cell INTEF. The result of background subtraction for single scans with subsequent transformation into the frequency domain is shown in (a). Four INTEF coadditions (b) before backgroud subtraction provide an enhancement of approximately two in the SNR.

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